

CNC3D Commander

Input Shaping & Backlash Compensation

User Guide

For CNC3D NightHawk PRO controllers

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1. Introduction

About this guide

This guide walks you through two advanced motion features on CNC3D NightHawk PRO controllers: Input Shaping and Backlash Compensation. Both features are built into the firmware and configured from the CNC3D Commander software. You do not need to edit any configuration files by hand.

Each feature has its own dedicated tab inside Commander. This guide covers, for each feature:

- What the feature does and what problem it solves.
- Where to find it in Commander.
- Exactly what every setting means.
- A step-by-step walkthrough of getting it dialled in.
- Common pitfalls, and how to recognise them.

If you want to understand the physics behind what these features are doing, there is a plain-English "What it all means" chapter at the back. You do not need to read it to use the features — but it will help you make sense of the numbers.

Who this guide is for

This guide is written for CNC owners and operators who already know how to run their machine, connect Commander, and execute G-code programs. You do not need any experience with input shaping or backlash compensation — we start from zero.

Before you start

IMPORTANT

Both features require a NightHawk PRO controller and compatible firmware. If the Input Shaping or Backlash Compensation tabs appear greyed out, check two things first: (1) you are connected to a PRO controller, and (2) your NightHawk firmware is up to date. The tabs are automatically enabled when both conditions are met.

You will also want:

- A machine that homes reliably. Input shaping calibration relies on accurate motion.
- A scrap piece of stock large enough for a small test cut (roughly 60 × 60 mm is plenty).
- A set of digital calipers capable of measuring down to 0.01 mm — for both features.
- Any end mill or router bit you would normally use for light cuts.

2. Input Shaping

What Input Shaping does

Every CNC machine has some flex in its frame, gantry, and drive train. When the cutter changes direction quickly — at the corner of a pocket, for example — that flex causes the tool to "ring" back and forth a few times before settling into the new direction. You can see this ringing as faint evenly-spaced marks just after a sharp corner.

Input Shaping is a technique borrowed from high-speed industrial machines. Instead of commanding a single sudden move and fighting the resulting oscillation, the firmware splits the move into a short sequence of carefully-timed pulses that cancel each other out. The tool still ends up in the same place, at the same moment, but the ringing is gone. The result is cleaner corners, fewer witness marks, and the ability to run the machine faster without sacrificing surface finish.

NOTE

Input Shaping is configured once per machine. You tune it once, save it to the controller, and it works silently in the background for every job after that.

Where to find it

Open CNC3D Commander and connect to your controller. In the main operations tabs along the top of the window, find the Input Shaping tab. If you do not see it, re-read "Before you start" above — the tab is hidden on non-PRO controllers and on out-of-date firmware.

The Input Shaping tab contains two sub-tabs:

- Settings — where the tuned values live for each axis. You can edit them by hand or let the wizard populate them.
- Calibration — the wizard that measures your machine's resonance and calculates the right values.

First-time users: go straight to the Calibration sub-tab. It does all the hard work for you.

The Settings sub-tab

Each axis on your machine gets its own row with three controls plus a couple of machine-wide options at the bottom.

Control	What it does	Valid range
Type	Which shaping algorithm to use for this axis. See "Choosing a Shaper Type" below.	ZV, ZVD, MZV or EI
Frequency (Hz)	The axis's natural ringing frequency, as measured by the calibration wizard.	10 – 200 Hz (default 40)

Damping Ratio	How much the axis naturally damps its own oscillation. Most CNCs sit around 0.01.	0.00 – 1.00 (default 0.01)
Enable Input Shaping	Master on/off toggle at the top of the tab. Turn this off to bypass shaping without losing your tuned values.	On / Off

Below the per-axis rows you will see two extra checkboxes:

- Use Accelerometer — only tick this if you have an accelerometer module fitted to the gantry. It lets the firmware auto-detect resonance in real time rather than relying on the tuned values.
- Auto-Calibrate every time when Home — if you also have the accelerometer, this runs a quick self-tune every time the machine homes. Useful if your part weight or fixturing changes between jobs.

TIP

You almost certainly do not have an accelerometer module on day one. Leave both of those checkboxes unticked, run the calibration wizard, and enjoy the benefits. You can always revisit the accelerometer options later if you add one.

The Calibration Wizard — step by step

The wizard is a three-step flow on the Calibration sub-tab. You configure it, let it make a small test cut, then measure the cut with calipers and let the wizard do the maths. Budget about ten minutes for the whole thing per axis.

IMPORTANT

Clamp a sacrificial piece of stock — wood, MDF, hard foam, anything easy to cut — firmly to the bed. The wizard will plunge into it and cut a small pattern. Make sure your Z-zero is set on the top of the stock before you start, and leave at least 5 mm of clearance around the cut area.

Step 1 — Configure the test parameters

Pick the axis you want to tune first (X and Y are the usual suspects). Set a feed rate (default 3000 mm/min is a good starting point — faster cuts produce clearer ringing marks), a test size (50 mm is plenty for most machines), and a cut depth (1.0 mm into soft stock is fine). These values are only used for this one test cut; they do not change your machine defaults.

Step 2 — Run the test cut

Click Run Calibration Test. The wizard streams a short G-code program to the controller. What it actually cuts depends on which axis you chose:

- X or Y: a small square with sharp corners. The ringing marks appear as evenly-spaced ripples just past each corner, running along the axis you are tuning.

- Z: a zigzag pattern with rapid plunge-and-retract motions. Ringing marks appear on the slot walls.
- A, B or C (rotary axes): repeated rotation reversals, leaving ringing marks on the cut surface.

Input shaping is automatically disabled during this cut — that is the only way to see the raw ringing and measure it. It turns back on as soon as the cut finishes.

NOTE

If nothing obvious appears in the test cut, your machine is already extremely rigid for its size. Try increasing the feed rate and running the test again; faster cuts expose ringing that slower cuts hide.

Step 3 — Measure and apply

Take the part off the machine, clean off the chips, and look at the cut edges with good light. You are looking for a repeating pattern of small ripples along the cut direction, with even spacing between peaks. Measure the distance between two consecutive peaks with your calipers and type that value into the Measured Ringing Spacing field. Then click Calculate Frequency. The wizard applies this formula:

$$\text{Frequency (Hz)} = \text{Feed Rate (mm/min)} \div 60 \div \text{Spacing (mm)}$$

You will see a frequency appear in big blue letters. If it sits between 10 and 200 Hz you are good to go — click Apply to Selected Axis and the value is copied into the Settings sub-tab for the axis you tested. If it is red, the measurement is outside the valid range; re-measure or try a different feed rate and run the test again.

Repeat Steps 1–3 for each axis you want to tune. X and Y are the most important; Z usually benefits too on lighter machines; rotary axes are optional.

Choosing a shaper type

The Type dropdown on the Settings tab gives you four algorithms. They are all valid choices — they just trade different things off. When in doubt, start with ZV and only change it if you have a specific reason.

Type	When to pick it
ZV	The classic. Fastest move time, but sensitive to mis-tuning. A solid default if your frequency measurement is accurate.
ZVD	More robust to small frequency errors than ZV, at the cost of slightly longer moves. Good if your measurement felt a little fuzzy.
MZV	Smoother acceleration profile. Pick this if you see surface quality issues on very fine details rather than ringing.
EI	The most forgiving — works well even if the frequency drifts by $\pm 10\%$. Pick this if your resonance changes a lot with fixturing or part

	weight.
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Tuning the damping ratio

Damping Ratio describes how quickly a ringing axis naturally settles on its own. Most CNC machines sit between 0.005 and 0.05. The default of 0.01 is a sensible starting point — leave it alone unless you have a good reason.

If you watch the test cut finish and see the ringing fade out almost immediately, you have higher damping — try raising the value toward 0.05. If the ringing rings on and on, lower it toward 0.005. In practice, the frequency setting matters much more than damping, so chase that first.

Applying the settings

Once the Settings sub-tab looks right, click Update Input Shaping Settings at the bottom. Commander streams every value to the controller one at a time and waits for confirmation after each one. When it finishes you will see a dialog telling you the update succeeded.

IMPORTANT

Always power-cycle the NightHawk after updating input shaping. The dialog will prompt you to disconnect; click Yes, then physically turn the controller off for a full five seconds before powering it back on and reconnecting. This lets the firmware fully re-initialise the motion planner with the new values.

Troubleshooting

A few things to check if input shaping is not behaving:

Tab is greyed out. Controller is not a PRO, firmware is out of date, or you are not actually connected. Check all three.

Update fails with an error. Usually means the firmware rejected one of the settings — typically a frequency outside the 10–200 Hz range. Re-check your values and try again.

Corners are still rough after tuning. The measured frequency was probably wrong. Run the calibration again with a higher feed rate (5000+ mm/min) so the ringing marks are clearer.

Machine sounds weirdly different but motion looks fine. That is normal. The firmware is issuing more frequent small step pulses. As long as cut quality improved, you are done.

Surface finish got worse, not better. Very rare. Double-check you entered the frequency in Hz, not the spacing in mm. A common mix-up.

3. Backlash Compensation

What Backlash Compensation does

Backlash is the tiny amount of "slack" you feel when you push a leadscrew or rack and it moves before the ball nut or pinion actually engages in the other direction. Every CNC has some — the question is how much, and whether it is enough to matter for your work.

When your machine reverses direction mid-job, that slack shows up as lost motion. A circle that should be round gets a flat spot at the quadrants. A dimensional pocket comes out undersized on one side. Pockets and profiles show steps where climb and conventional cuts meet.

Backlash Compensation tells the firmware to quietly take up that slack every time an axis reverses. The motor moves a tiny extra distance in the new direction before any cutting happens, so the tool tip ends up exactly where the G-code asked. No more flat-spotted circles.

NOTE

Compensation only activates on direction reversals. Continuous motion in one direction does not trigger any extra movement — the feature is silent unless it needs to be active.

Where to find it

The Backlash Compensation tab lives in the same operations area as the Input Shaping tab. Like input shaping, it is only enabled on NightHawk PRO controllers with up-to-date firmware.

Measuring backlash on your machine

Unlike input shaping, there is no automated wizard for backlash. You measure it yourself with a dial indicator (best) or a pair of digital calipers against a hard edge (good enough). Do this once per axis, then type the numbers into Commander.

Rough procedure:

1. Set up a dial indicator touching a hard feature on the axis you want to measure — typically the gantry side or the spindle body.
2. Jog the axis slowly in the positive direction by 5 mm. Zero the indicator.
3. Jog the axis 1 mm further in the positive direction, then 1 mm back. The indicator should return to zero. If it does, your negative direction is fully seated.
4. Now jog the axis 1 mm in the negative direction. Watch the indicator — it should start moving immediately. Any delay before it moves is backlash.
5. Read the indicator when the axis finishes its 1 mm move. Anything less than 1.000 mm shown on the indicator means the missing amount is backlash. For example, if the indicator reads 0.963 mm, backlash is 0.037 mm.
6. Jog back and forth a few times to confirm — the number should be consistent within about 0.002 mm.

TIP

Repeat the process for each axis you want to compensate. Most routers have a bit of backlash on all of X, Y and Z, but usually nothing dramatic (under 0.05 mm). If any axis shows more than about 0.1 mm, you have a mechanical issue — a loose pulley, worn ball nut, or over-tightened belt — that compensation will not fully fix.

Entering values and selecting axes

The Backlash Compensation tab shows one row per axis. Each row has a checkbox (X, Y, Z and so on) and a numeric field labelled in millimetres. Tick the axes you measured, type the measured values in the fields next to them, and tick the master Enable Backlash Compensation checkbox at the top.

You can enter values to three decimal places — down to 0.001 mm. Valid range is 0 to 50 mm, but in practice anything over a tenth of a millimetre probably warrants a look at the mechanics.

Applying the settings

Click Update Backlash Settings. Commander streams your values to the controller and waits for an acknowledgement between each one. When it finishes you will see a dialog confirming success and asking whether you want to disconnect for a reboot.

IMPORTANT

As with input shaping, power-cycle the NightHawk after updating. Five seconds off, then back on. Reconnect and the new values are active.

What happens under the hood

After you apply the settings, the firmware starts tracking direction for each compensated axis. When it sees a reversal it adds your configured distance to the motor target, so the motor moves a tiny bit further than the G-code asked — enough to take up the slack. The reported tool position remains correct, so homed coordinates are not affected.

After homing, the compensation offset resets to zero and is rebuilt from scratch as soon as the first reversal happens. This prevents compensation errors from accumulating across jobs.

Troubleshooting

Circles still have flat spots at the quadrants. Measured backlash is too low. Re-measure with a dial indicator — calipers against an edge often under-read.

Pockets are slightly undersized on one side. Almost certainly residual backlash. Increase the value on the affected axis by 0.005 mm at a time until the error vanishes.

Machine 'jumps' slightly on reversal. Backlash value is too high — you are overshooting. Reduce it, or re-measure.

Values never save. Look at the message area for an error from the firmware. Usually means an out-of-range value or a dropped serial message — reconnect and try again.

Compensation works on X/Y but not Z. Check that the Z checkbox is ticked on the tab. Each axis has its own enable.

4. What it all means — the plain-English version

This chapter is optional. If your machine is cutting well after running the wizards, you are done. Read on if you are curious about what is actually happening inside the controller.

Why CNC machines ring

Think of your machine as a big spring with a cutter attached to the end. The spring is made up of every belt, ball-screw, rail and frame member between the motor and the tool. When the motor commands a sudden direction change, the frame twists very slightly, the gantry bends a hair, and the tool tip lags behind for a fraction of a second. Once the motion stops, the frame releases that stored energy — and the tool oscillates back and forth around the commanded position a few times before it settles.

The frequency of that oscillation depends on the machine: frame stiffness, gantry mass, and the drive system all matter. A small router might ring at 80 Hz; a big, heavy industrial machine might ring at 20 Hz. That is why we measure the frequency per machine, per axis — yours is unique.

How input shaping cancels ringing

Here is the neat trick. If you know your machine rings at a particular frequency, you can predict exactly how it will respond to a sudden kick. So instead of one big kick, you split the command into two (or three, or four) smaller kicks, carefully timed.

The first kick starts the axis moving and kicks off a bit of oscillation. The second kick is timed precisely so that its oscillation cancels the first one — the peaks of one line up with the valleys of the other. The net result: the tool arrives at the commanded position without ringing.

Different shaper types (ZV, ZVD, MZV, EI) are different recipes for how many kicks to use and when to fire them. They trade off speed, robustness, and how precisely you need to know the frequency. The firmware does all this in real time, invisibly.

What backlash actually is

Picture a ball-screw. A rotating screw pushes a nut along its length; the nut is attached to the moving axis. For the nut to push, the balls inside have to be in contact with one flank of the screw thread. When the screw rotates the other direction, the balls have to roll across to the other flank before any movement happens. That rolling across is backlash.

Belts, pinions, couplings and flexible joints all add their own small amounts. On a well-maintained machine it might be 0.02 mm; on a worn one, 0.2 mm or more. It only shows up on direction reversals, which is why cutting one-way finishes look fine while pockets and bores look sloppy.

Why compensating helps

Mechanical backlash is hard to eliminate. Tightening belts too much wears bearings prematurely; upgrading ball-screws is expensive. The cheap, software-only fix is to tell the controller: "whenever this axis reverses, push the motor an extra 0.03 mm quietly before you expect it to cut." From the part's perspective, the backlash is gone.

It is not perfect — backlash that varies with cutting load, for example, is tricky to compensate with a single fixed number. But for most hobbyist and prosumer machines, compensation gets you within a hair's breadth of no backlash at all.

Appendix A — Settings reference

These are the underlying firmware settings that the two tabs configure. You never need to type these by hand; they are listed here for reference only.

Input Shaping

Setting	Range	Purpose
<code>\$IS/Enable</code>	On / Off	Master enable for input shaping.
<code>\$IS/Type/{X,Y,Z,A,B,C}</code>	0–3	Shaper type per axis. 0 = ZV, 1 = ZVD, 2 = MZV, 3 = EI.
<code>\$IS/Freq/{X,Y,Z,A,B,C}</code>	10–200 Hz	Resonant frequency per axis.
<code>\$IS/Damp/{X,Y,Z,A,B,C}</code>	0.00–1.00	Damping ratio per axis.
<code>\$IS/Accel/Enable</code>	On / Off	Enable accelerometer-driven real-time shaping.
<code>\$IS/Accel/AutoCal</code>	On / Off	Auto-calibrate on home (requires accelerometer).

Backlash Compensation

Setting	Range	Purpose
<code>\$BLComp/Enable</code>	On / Off	Master enable for backlash compensation.
<code>\$BLComp/Axes</code>	"X", "XY", ...	Which axes compensation applies to, expressed as a letter string.
<code>\$BLComp/{X,Y,Z,A,B,C}/Mm</code>	0–50 mm	Backlash distance per axis, in millimetres.

Appendix B — Glossary

Backlash. Lost motion when an axis reverses direction, caused by play in screws, nuts, belts or couplings.

Damping Ratio. How quickly a ringing axis settles on its own. Most CNCs sit around 0.01.

EI (Extra Insensitive) shaper. An input shaper recipe that works well even when the measured frequency is slightly off.

Frequency (Hz). Cycles per second. In input shaping, it is the natural ringing frequency of an axis.

Input Shaping. A motion-planning technique that cancels machine ringing by splitting sudden direction changes into timed pulses.

MZV (Modified Zero Vibration) shaper. An input shaper recipe that trades a slightly longer move for smoother acceleration.

NightHawk PRO. CNC3D's professional-grade controller variant. Required for both input shaping and backlash compensation.

Resonance / Ringing. The tendency of a mechanical structure to oscillate at its natural frequency after being disturbed.

Shaper Type. Which input shaping recipe the firmware uses: ZV, ZVD, MZV or EI.

ZV (Zero Vibration) shaper. The classic two-pulse input shaper. Fast but needs an accurate frequency measurement.

ZVD (Zero Vibration Derivative) shaper. A three-pulse variant of ZV that is more robust to measurement error.